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CNGS Extraction and Transfer Stability in 2007

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Abstract

During the two week SPS operation period for CNGS in October 2007 approximately 47'000 extractions were recorded with an average intensity on target of 1.7×10^{13} protons per extraction. Although this period was rather short it presented an excellent opportunity to study the stability and performance of the primary CNGS beam from extraction to target. This document presents results on beam position stability and beam losses for the CNGS running period. The beam stability on target over the 15 day period was found to be excellent and well within the tolerance for target protection. Beam losses on the extraction septa could be maintained at a low level for the entire period. The analysis of the interlock system data revealed no malfunctioning of the interlock system. It revealed however that in stable periods 3% of the extractions were not triggered and that false interlocks were the cause of most of the missing extractions.

Geneva, Switzerland

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1 Introduction

The CERN Neutrino Beam to Gran Sasso has been commissionned in the summer of 2006 [1, 2] and a six weeks CNGS beam period was scheduled for the fall of 2007.

The high intensity CNGS beam has the potential to damage transfer line equipment. The CNGS target (T40) itself may be damaged in case it is hit repeatedly by the beam with offsets larger than 0.5 mm from its axis. To prevent any damage to the equipment the transfer line is protected by an extensive and fast beam interlock system. All power converters are interlocked with very tight tolerances. The beam position is interlocked on all position monitors of the transfer line. Beam loss monitors protect the extraction channel and the transfer line [3, 4]. A software based interlock system (SIS) provides additional protection for the CNGS transfer line and target [5]. The SIS will stop the CNGS beam production in the SPS injectors whenever the beam cannot be extracted. Due to the tight interlock settings the CNGS beam availability depends strongly on the beam stability in position and on low losses.

This document presents an analysis of the transfer stability in terms of position and losses. In the first sections, the beam setup and characteristics are presented. The following two sections are devoted to the stability of the beam in the SPS ring before extraction and in the transfer line. Finally the stability of the beam losses is presented. Extractions lost due to false interlocks are discussed at the end of the document.

2 CNGS Transfer Line Setup

The CNGS beam operation period started in the middle of September 2007 and ended October 20th 2007. The first beam was send to the T40 target in the evening of September 21^{th}. The beam reached the target immediately and a few iterations were sufficient to obtain a well corrected trajectory. The main magnets settings were fully reproducible as compared to 2006, and all the major corrections (excluding the trajectory correction magnets) were identical in 2006 and 2007. Those corrections are indicated in Table 1. The nominal transfer line momentum was again set to 398.5 GeV/c because the “true” beam energy of the SPS is slightly lower than its nominal value of 400 GeV/c. The phase advance of the TT41 arc cells was again found to be larger than nominal, and the correction introduced in 2006 was applied again [8], see the last two lines of Table 1.

In the following days the beam was aligned to the target with the muon detectors, the aperture and optics was verified and the interlock system was checked. The momentum aperture was determined to be larger than $\pm 0.6\%$, the measurement being limited in the SPS ring itself. For all dipole and quadrupole converters the interlock settings of 2006 could be reproduced to better than 0.1%, confirming the excellent stability of the line and of its equipment [3, 6, 7].

3 CNGS Beam

3.1 Beam Structure

The measured longitudinal structure of the CNGS beam is shown in Figure 1. It consists of two 10.5 μs long batches injected from the PS at 14 GeV/c using a continuous 5 turns transfer. The

Circuit	Correction	Comment
MSE.418	$-24.3\ \mu$rad	Extraction septum angle
RBIH.410101	$+20.0\ \mu$rad	MBHC dipole string
RBI.410010	$-27.5\ \mu$rad	MBSG switchyard dipole string
RQIF.400400	$-2 \cdot 10^{-4}$ m^{-2}	Main F quadrupole family phase advance correction
RQID.400300	$+3 \cdot 10^{-4}$ m^{-2}	Main D quadrupole family phase advance correction

Table 1: Strength corrections for the main CNGS circuits. All corrections correspond to individual magnets, and not to the integral of the magnet string.

batches are separated by two equidistant 1 μm long gaps without beam. The two batches are extracted at 400 GeV/c at an interval of 50 ms by a fast extraction kicker.

To avoid beam loss during extraction the two beam gaps must be free of particles. The beam population in the gapsis minized by a capture at 14 GeV/c with a total RF voltage of 800 kV. 50 ms after injection of the first batch, the RF voltage is ramped to 1200 kV and ramped down again to 800 kV for the second injection that is injected 1.2 seconds later. This voltages program minimizes the capture losses, but is not always sufficient to ensure clean gaps. For that reason the injection kicker was used as an additional measure to clean the gaps. For the second injection, the injection kicker pulse was advanced by 250 ns to clean the gap in front of the second batch from any beam that would be present due to imperfect capture of the first batch. This frequently leads to losses of $\approx 1\%$ at injection. This 'advanced' kicker pulse turned out to provide a rather stable and low gap population.

The normalized transverse beam emittance for the highest intensities was $8 - 10\ \mu$m in both planes. During commissioning the emittances were in the range of $2 - 4\ \mu$m for a batch population of $2 - 5 \times 10^{12}$ protons.

3.2 Beam Intensities

The data sample that has been analyzed covers the period starting October 5th and ending with the last CNGS beam. This period corresponds to rather stable operation (except for stops due to radiation issues). The SPS super-cycle was composed of a fixed target cycle with a long extraction flat top, three CNGS cycles (mapped to SPS timing users CNGS1, CNGS2 and CNGS3) and an ion MD cycle. The total super-cycle length was 39.8 seconds. In that 15 day period 46'500 extraction were recorded in 23'700 cycles. The intensity distribution of the extracted batches is shown in Figure 2. The maximum intensity approached 2×10^{13} protons.

The total intensity on target of this period is 7.8×10^{17} protons. This corresponds to 93% of the total intensity delivered to T40 in 2007. A comparison with the SPS BCT indicates that in stable periods about 2% of the first and 3.6% of the second extractions are not triggered:

- In 1% of the cycles both extractions are missing.
- In 1.1% of the cycles the first extraction is missing.
- In 2.5% of the cycles the second extraction is missing.

In stable periods one or both extractions are missing in 4.6% of the cycles The cause of those missing extractions will be discussed later.

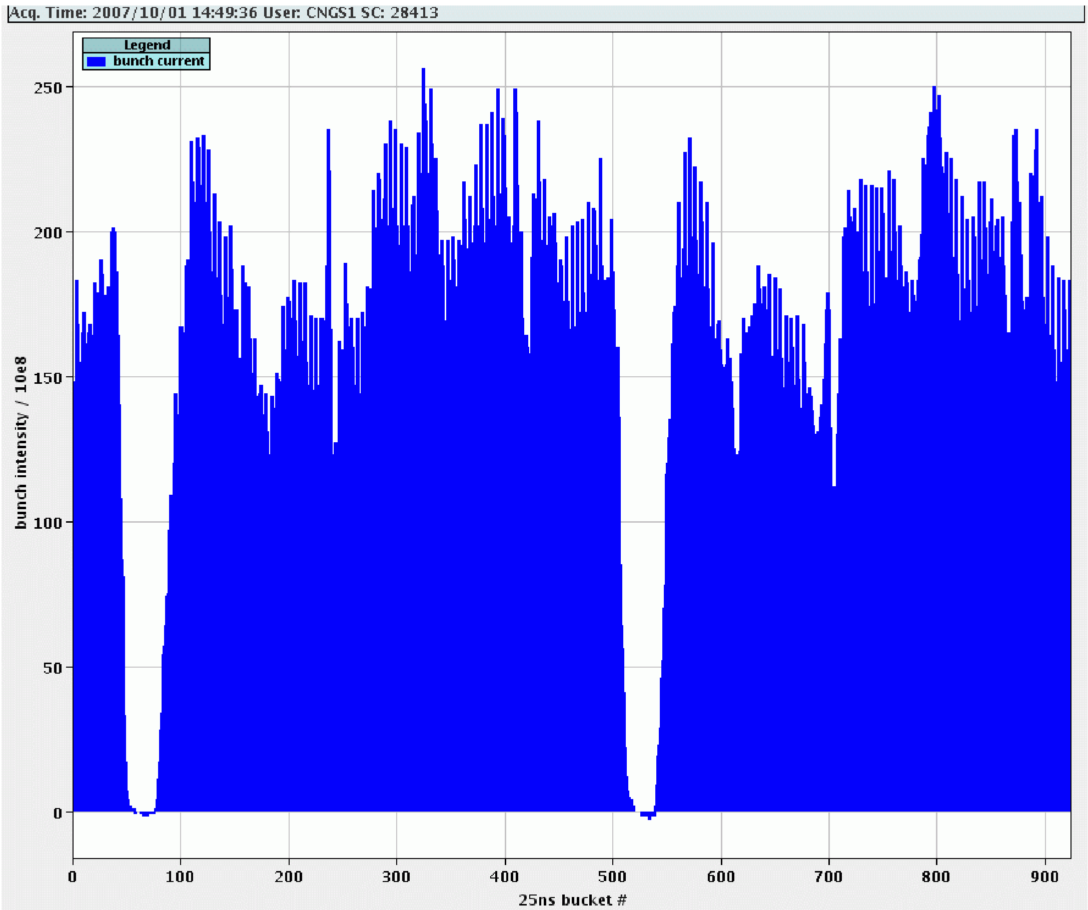


Figure 1: Structure of the CNGS beam with two 10.5 μs batches separated by two 1 μm gaps. Each bin gives the intensity integrated over 25 ns, respectively 5 bunches. The intensity variations within a batch due to the 5 turn extraction from the PS is clearly visible.

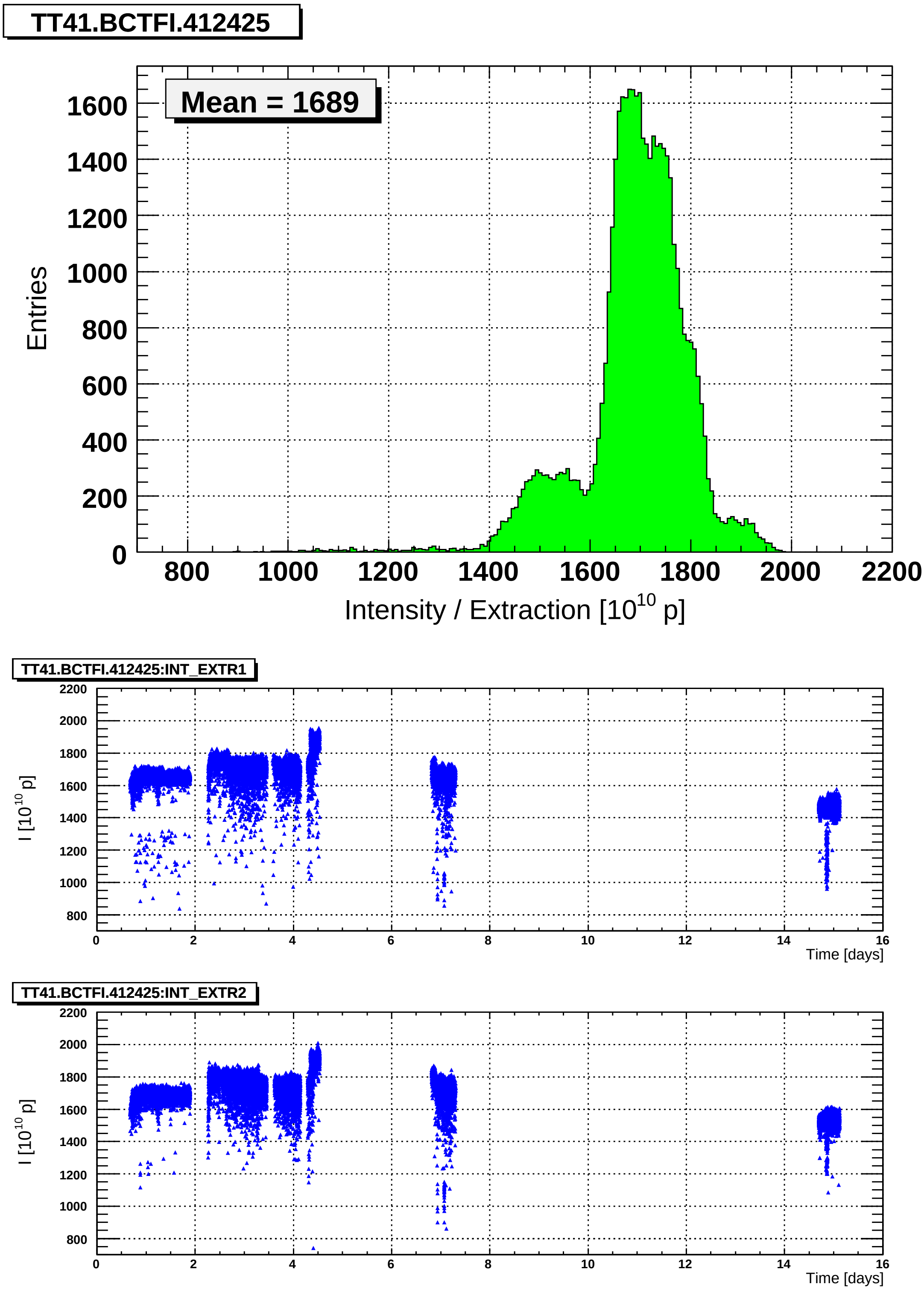


Figure 2: Batch intensity distribution (top) and time evolution (for extraction 1 and extraction 2) for the period that has been analyzed in the note..

4 SPS Beam Position Stability

To ensure a stable position in the extraction channel, in the transfer line and on target, the position of the SPS beam is measured approximately 50 ms before each extraction. The measurement is interlocked with a tolerance of ± 1 mm at SPS beam position monitor (BPM) BPCE.41801 which is located close to the maximum amplitude of the horizontal extraction bump. Five nearby BPMs are also interlocked, but with looser tolerances of ± 2 mm. Projected on the target, the interlock tolerances correspond to a position range of $\approx \pm 0.3$ mm.

At top energy the SPS orbit corrector magnets are too weak to provide a useful means of correcting the SPS orbit which is therefore left uncorrected for the duration of a run. Only an initial correction is performed during each startup period: the raw orbit r.m.s. is measured and corrected by re-aligning appropriate machine quadrupoles until the r.m.s. orbit is better than 2 mm in each plane. The stability of the high energy orbit in the SPS is excellent, with drifts of no more than 1-2 mm over the course of a run.

The stability of the CNGS beam position before extraction is shown in Figure 3. The average horizontal position is 33.1 mm. It corresponds to a nominal extraction bump setting of 32 mm. The two peaks visible in Figure 3 are due to a systematic difference of the measured position for the CNGS3 cycle with respect to the CNGS1 and CNGS2 cycles. This is most likely due to a small difference of the BPM calibration factors for that cycle. The intrinsic width of each peak is less than 0.1 mm, which is consistent with the expected beam stability in the SPS at 400 GeV. During the 15 day period the beam position at the extraction point was never adjusted.

The isolated measurements that are significantly below (and sometimes also above) the main band on the time evolution plot are due to erroneous measurements. They lead to a false interlock on the extraction since the positions are significantly outside the tolerance window. A simple analysis based only on the measured position indicates that approximately 0.1% of the first and 0.6% of the second extractions should have been interlocked due to an incorrect beam position measurement. In reality, as will be shown later, over 2% of the cycles had one or both extractions interlocked by the SPS position measurement. The cause seem to be large timing jitters of many tens of milliseconds in the BPM front-end system.

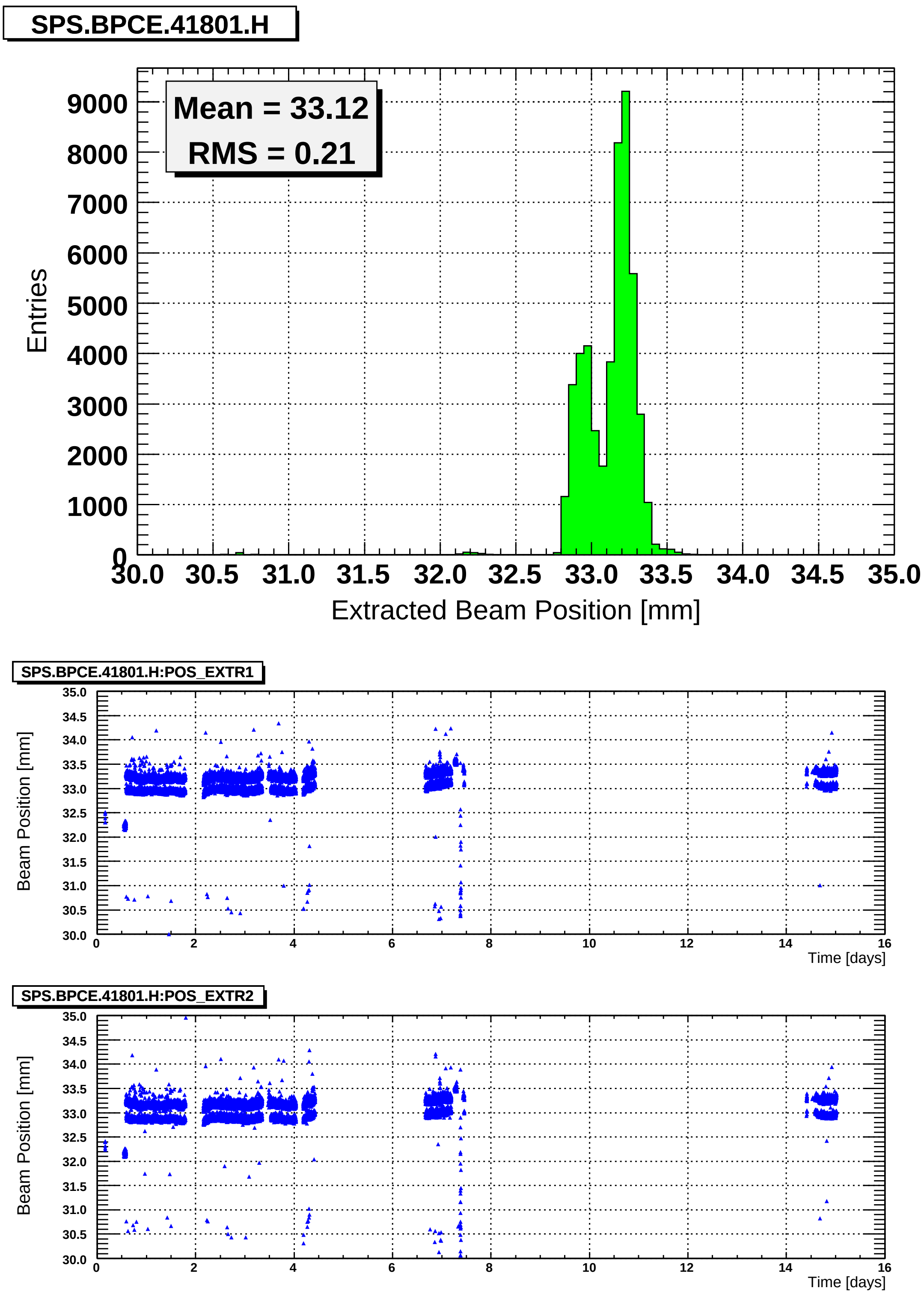


Figure 3: Horizontal beam position of the SPS beam before extraction measured by BPM BPCE.41801.

5 Target and Transfer Line Beam Position Stability

The beam position in the TT40 and TT41 transfer lines is measured with 23 BPMs with self-triggered electronics. Four monitors (couplers) are installed in TT40, 19 monitors (18 electrostatic buttons and one coupler) are installed in TT41. The last monitor (BPKG.412249) is a coupler operating in air and not under vacuum that is mounted on the target station. The self-trigger requires a minimum beam density corresponding to a batch of 10^{12} protons concentrated over $2 - 3$ μs (one PS turn).

The average positions at all monitors in TT41 over the analyzed period are shown in Figure 4. All positions are well within the design tolerance of ± 4 mm. The transfer line tunnel of the CNGS transfer line is very stable, and the trajectory is not expected to drift significant over a period of two weeks [8]. Trajectory corrections were not required more than once per week on average. For that reason no automated feedback is need to stabilize the beam on target.

The beam positions are interlocked with respect to a reference trajectory with tolerances of $\pm$ 4 mm for all BPMs except the last 4 monitors in front of the target where the tolerance is reduced to $\pm$ 1 mm (fourth and third monitor from target) and to $\pm$ 0.5 mm for the last 2 monitors. The measurement of the beam position at the last monitor BPKG.412249 mounted on the target station is used here to quantify the extraction stability.

The stability of the beam position measured by the BPKG is shown in Figures 5 to 7 for the two CNGS extractions. The trajectories of the two extractions only differ due to a small relative energy difference of the extracted batches of the order of 10^{-4}. This difference is due to the fact that the SPS main dipole converter cannot provide a stable current on a flat top that is as short as the 90 ms of the CNGS cycle. On the time evolution plots, one notices adjustments of the position at the target to maintain the beam centered in the muon detectors. Slow drifts are also visible, in particular in the vertical plane. The overall stability is excellent, with all position recordings well within a window of $\pm$ 0.5 mm.

The comparison of the first and the second extraction gives an indication of the intrinsic extraction stability. The r.m.s. values of the distributions are 50 μm in the horizontal and 20 μm in the vertical planes, which corresponds to a stability of 30 and 15 μm per extraction. The larger width of the horizontal distribution is due to the ripple on the extraction septum MSE.418 [8]. It must also be noted that BPM measurement noise also contributes to those values. The correlation of horizontal and vertical position is shown in Figure 8 where one can observe a clear correlation between the two planes, with a slope $\Delta Y/\Delta X$ close to 0.4 to 0.5. This strong correlation is not understood, in particular because so such correlation is observed when the beam is steered locally in front of the target or when the response of the beam to corrector kicks is performed. In addition one also observes that when the positions have large offsets, the offsets appear in both planes.

5.1 Position Interlocks

On 4 occasions during the analyzed period, the beam position was outside the interlock tolerance on at least one monitor, always for the second extraction. A detailled analysis of those events shows that they correspond to erroneous trajectory measurements that usually affected a significant fraction of the monitors. Those events lead to beam position interlocks that had to be reset manually by the operators. The beam interlock data logging confirms the results of the position analysis. No inconsistency was found between position measurements and interlock system recordings. Furthermore the Software Interlock Systems stopped the beam in the SPS as soon as a position interlock was recorded, again confirmed by the logging data from the SPS BCT and the beam interlock system.

During the setup period (i.e. outside the period considered for this analysis), a position interlock was triggered on 29-09-2007 18:34:15 local time. This event corresponded to a real event and not not a measurement error. The batch intensity was close to $5 \cdot 10^{12}$ protons. The trajectory excursion with respect to the reference is shown in Figure 9. The interlock was triggered by monitor number 21 where the position just exceeded the 1 mm tolerance window. At the level of the target the beam excursion was just below the limit of 0.5 mm. A clean betatron oscillation is visible in the horizontal plane. Its origin must be in the SPS ring or in the extraction channel. The phase advance is consistent with a kick originating from the MKE extraction kicker. From earlier calibration such a trajectory may be produced by a kick at 48 kV instead of the nominal 50 kV, i.e. just at the limit of the Beam Energy Tracking System interlock threshold. This hypothesis could however not be confirmed from the logged data.

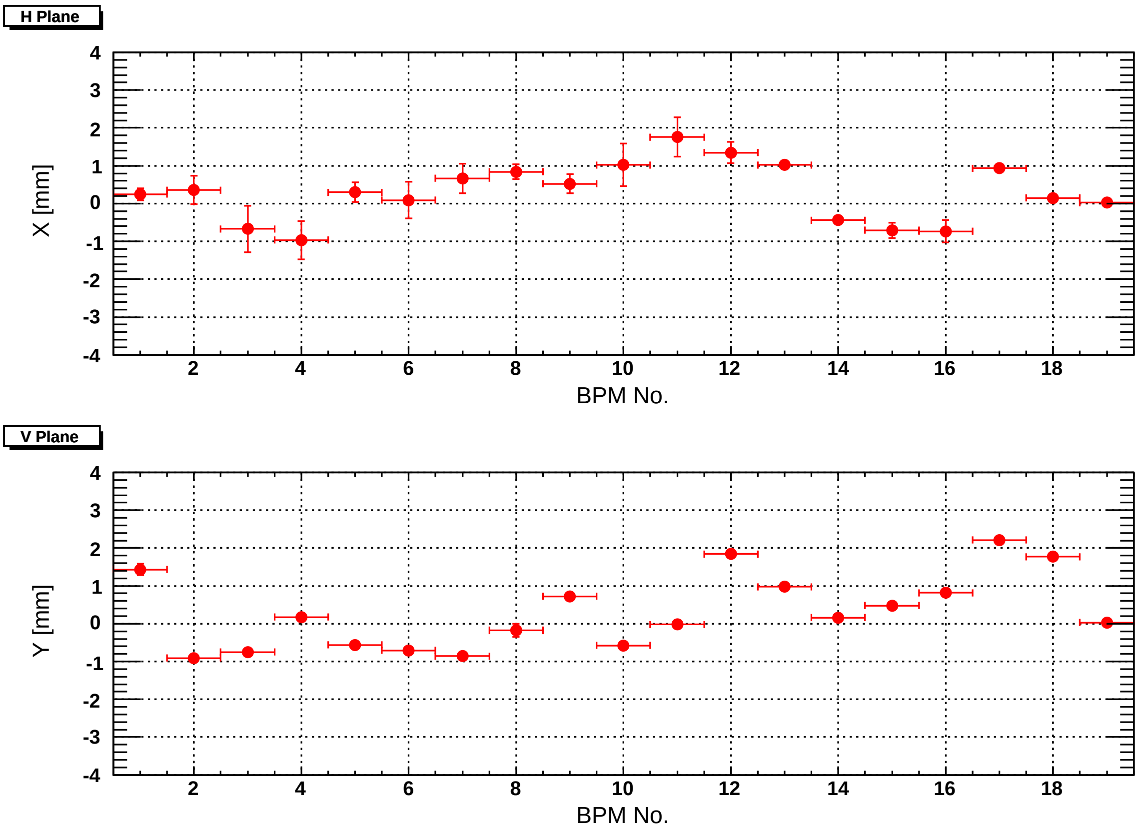


Figure 4: Average beam positions for all TT41 monitors. The error bars correspond to the RMS spread of the positions. The last monitor (no. 19) is an air coupler mounted directly on the target station.

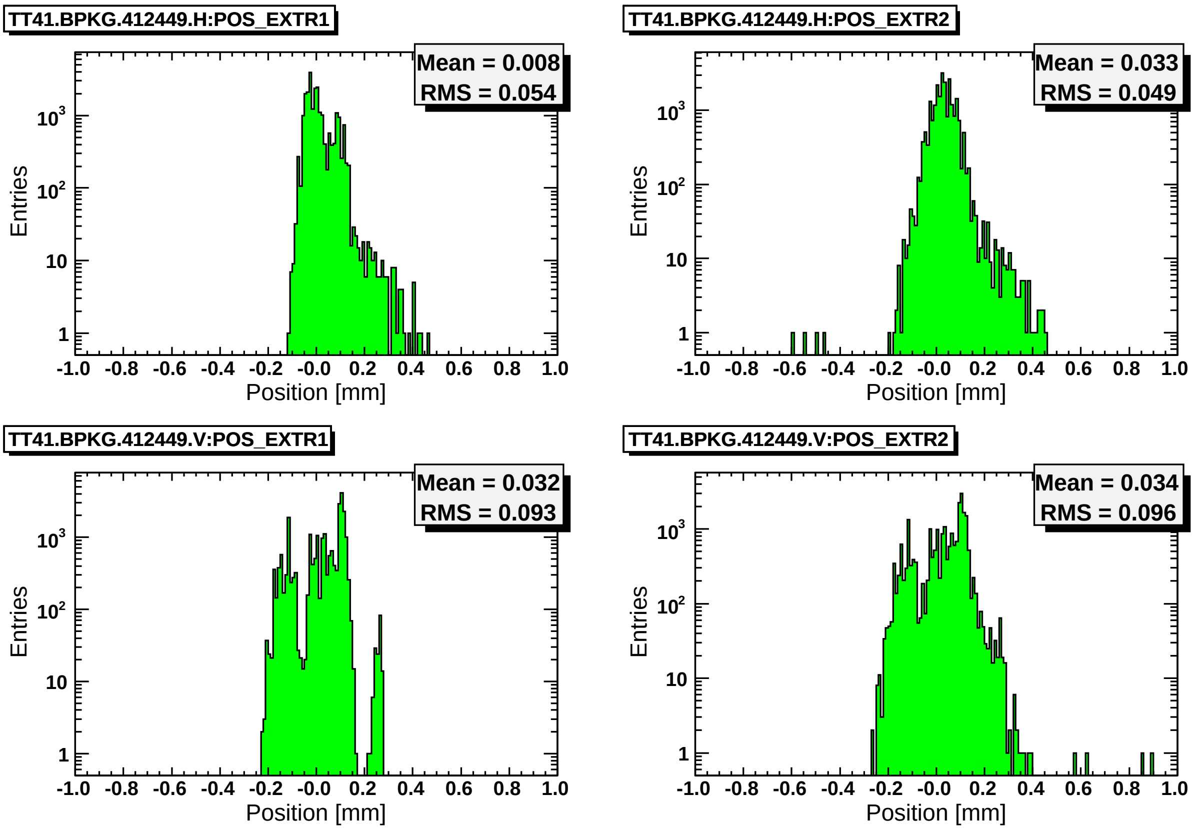


Figure 5: Beam position distribution for both planes and extractions on the last BPM BPKG.412449 in front of the T40 target. One notes that the distributions for the second extraction are larger than for the first extraction, see also Figure 6. The multiple peaks in the vertical planeare due to target steering.

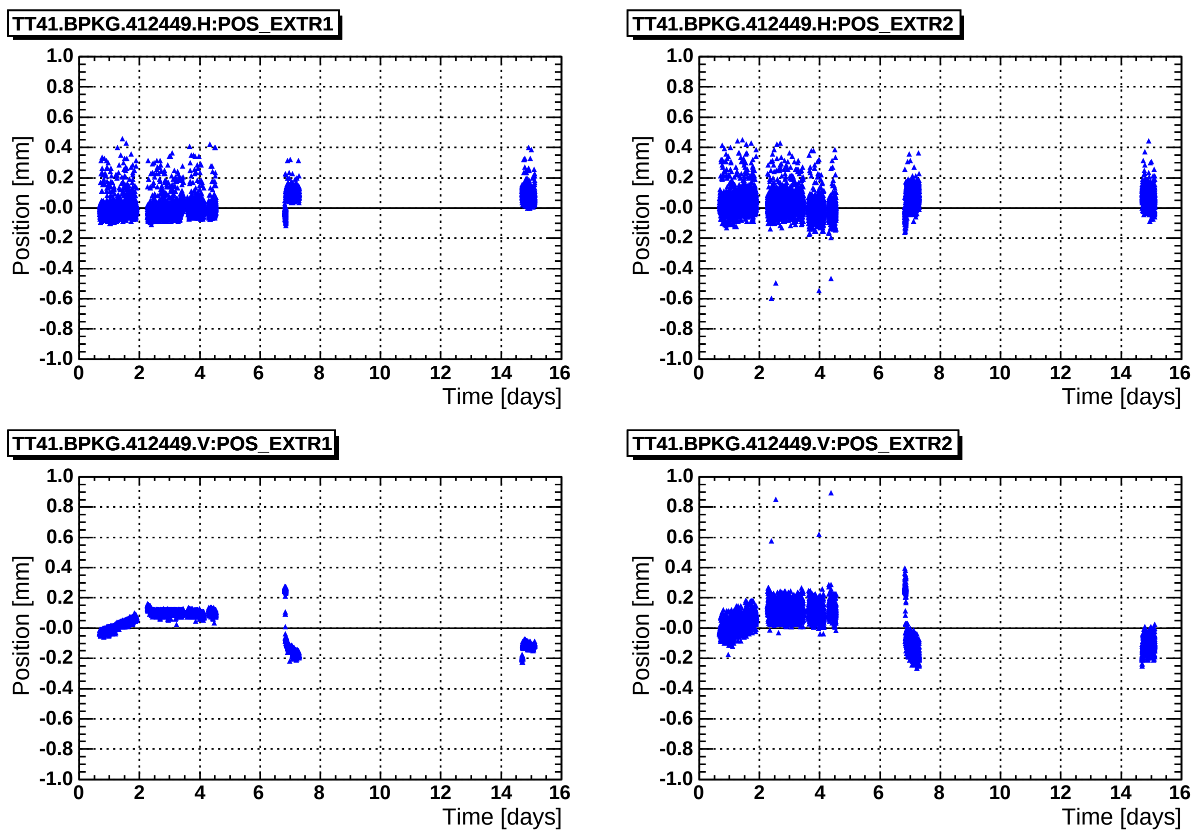


Figure 6: Beam position evolution versus time both each plane and extraction on the last BPM BPKG.412449 in front of the T40 target.

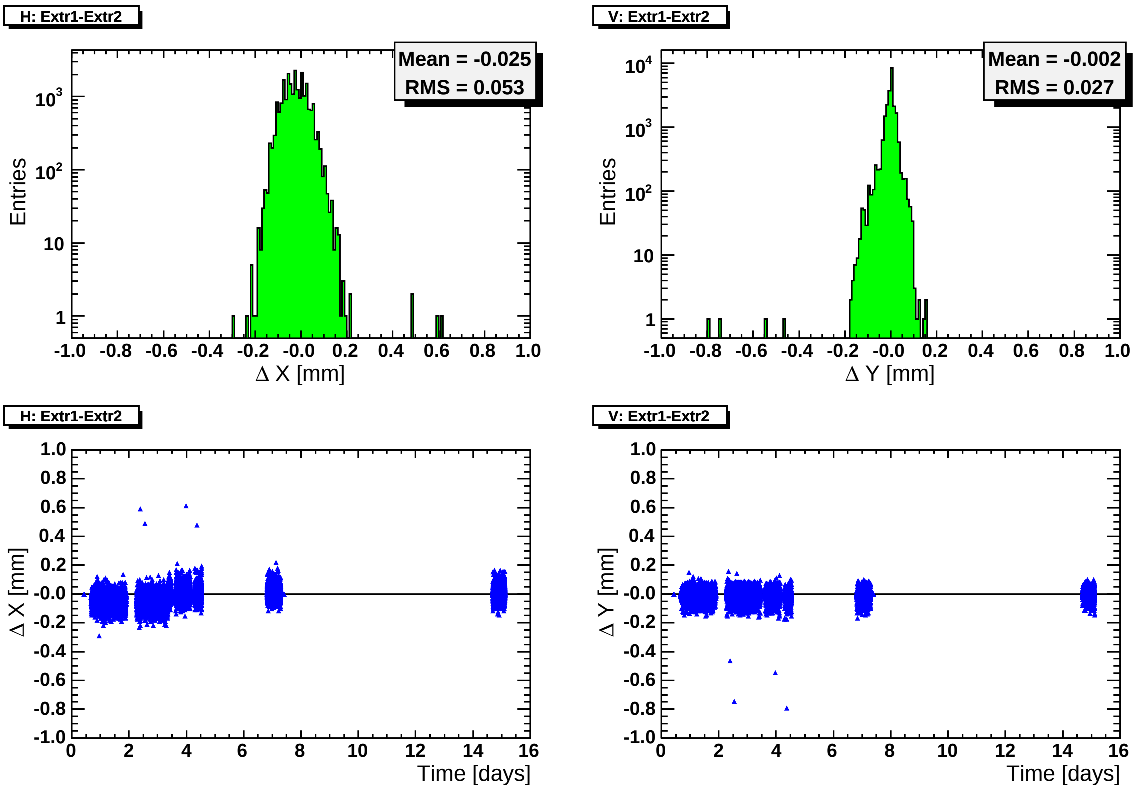


Figure 7: Distribution and time evolution of the beam position difference between the second and the first extraction for the last BPM BPKG.412449 in front of the T40 target.

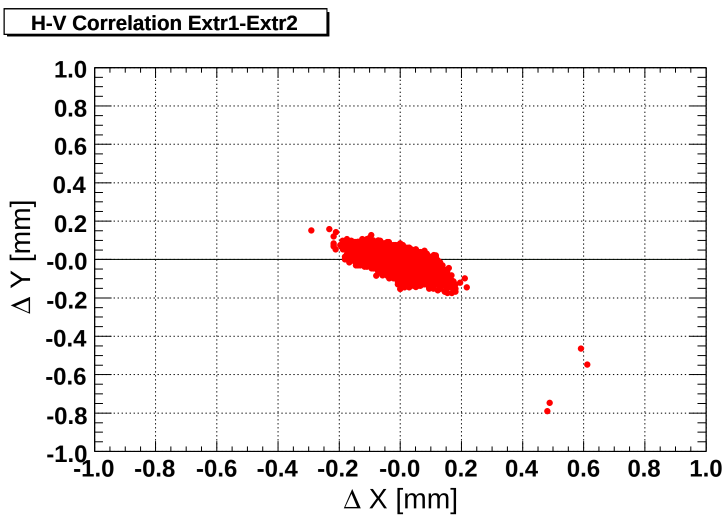


Figure 8: Correlation of the horizontal and vertical position at BPM BPKG.412449. One notes a correlation between the two planes that is not observed in response measurements or during target steering.

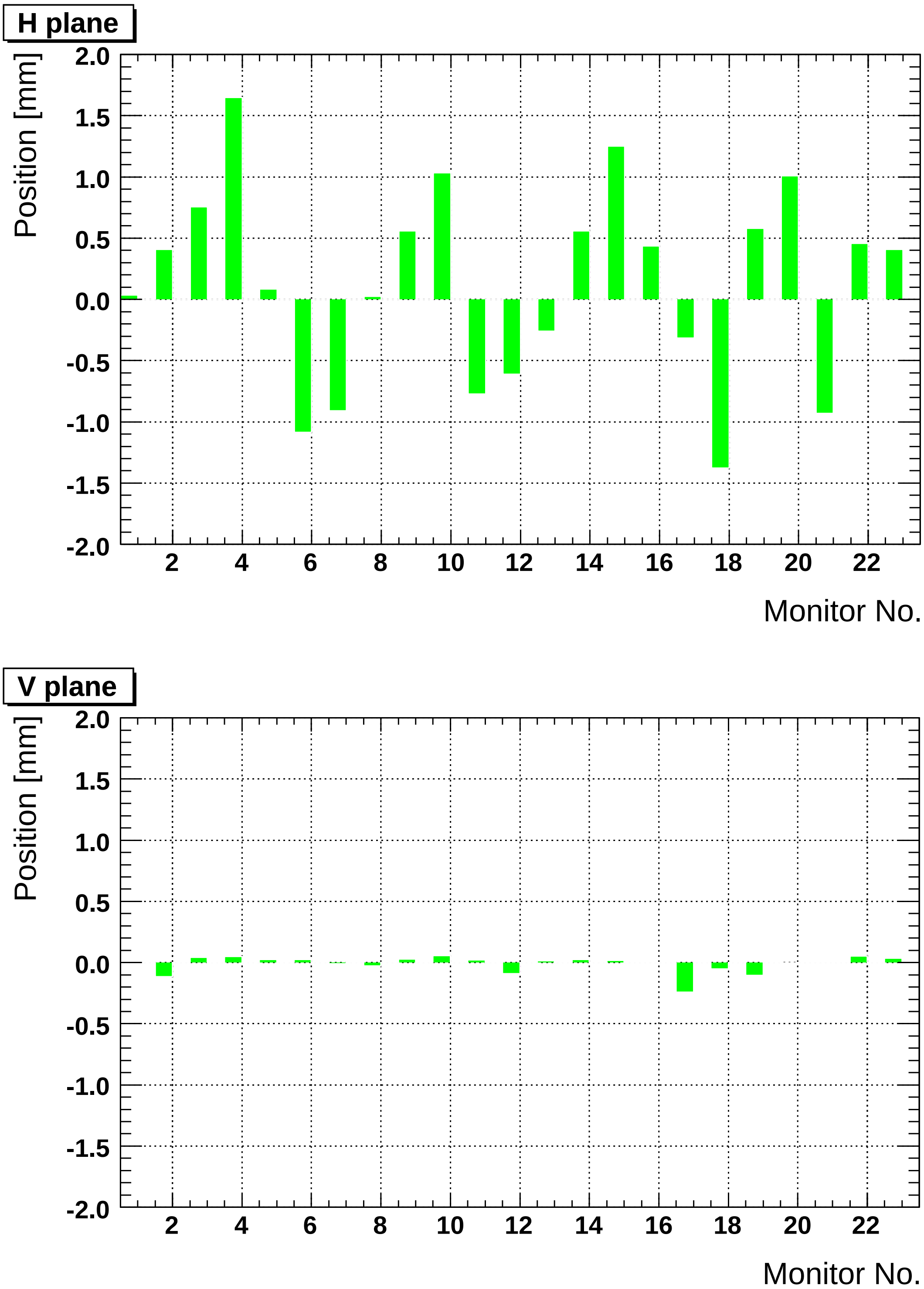


Figure 9: This trajectory recorded on 29-09-2007 18:34:15 local time triggered an interlock on the beam position (trigger from BPM number 21 in the horizontal plane). It is shown as a difference with respect to the reference trajectory. In the horizontal plane there is a clean betatron oscillation originating from the SPS ring or from the extraction channel.

6 Beam loss

The beam loss monitor (BLM) system for CNGS is separated into two distinct systems:

- The extraction BLM system includes 8 monitors installed along the extraction channel. When such a monitor triggers an interlock because the loss exceeds the threshold, the circulating SPS beam is dumped, because this system must also protect the extraction channel against losses from the circulating beam. When such a dump trigger occurs after the first extraction, the beam is dumped and the second CNGS extraction is obviously missing. The interlock is reset at the end of the cycle. The SPS Software Interlock System (SIS) latches the interlock after three consecutive interlocked cycles. The SIS latch must be reset manually by the operation crews after investigation of the problem.
- The transfer line BLMs inhibit the extractions whenever a monitor observes a loss above threshold. The interlock is latched and must be reset manually by the operation crews.

6.1 Extraction channel losses

The beam structure with two 10.5 μs long batches separated by two gaps of only 1 μs (Figure 1) poses tight constraints on the extraction kicker risetime and on the residual particle density in the beam gaps. Incorrect kicker pulse synchronization (delay or length) and excessive beam gap populations may lead to excessive beam losses in the extraction channel.

The largest bean loss is always observed on the first extraction BLM which is installed near the TPSG absorber. The TPSG is a thin carbon absorber installed in front of the MSE septum edge. Its role is to protect the extraction septum in case of the kicker failure and it is designed to protect the septum against damage from the impact of a nominal CNGS extraction. When the extraction septa girders are well aligned, beam in the gap between the batches is mostly lost on the TPSG [2]. The measured losses on the BLM installed next to the TPSG are shown in Figure 10. The typical loss of 17 mGray for both extractions corresponds approximately to 1.7×10^{10} protons, or 0.05% of the extracted intensity (10 mGray correspond approximately to 10^{10} protons lost on the TPSG [2]). The interlock threshold on this first loss monitor is set to 40 mGray, i.e. about two times higher than the 'normal' loss. The loss on the second extraction is normally smaller, because most of the beam in the gaps is 'cleaned' by the first extraction. The correlation of the losses between the two extractions is shown in Figure 11. For large losses on extraction 1, there is no loss for extraction 2 because the beam dump is triggered by the BLM. The large losses on extraction 2 correspond to cases where extraction 1 was not triggered due to an interlock (1% of the extractions). In such an event the loss on the second extraction has the same level than the loss on the first extraction.

Extractions with larger than normal beam loss occur randomly over time. The interlock was never latched by SIS because there were never two consecutive cycles with high losses. The fraction of first extractions that lead to a beam dump due to high losses is 0.3%. There is a correlation between high losses in the extraction channel and cycles with lower intensity, see Figure 11. Such cycles are correlated to lower intensity or poor beam structure from the CPS, leading to losses at injection, larger losses at capture and/or in the early part of the ramp.

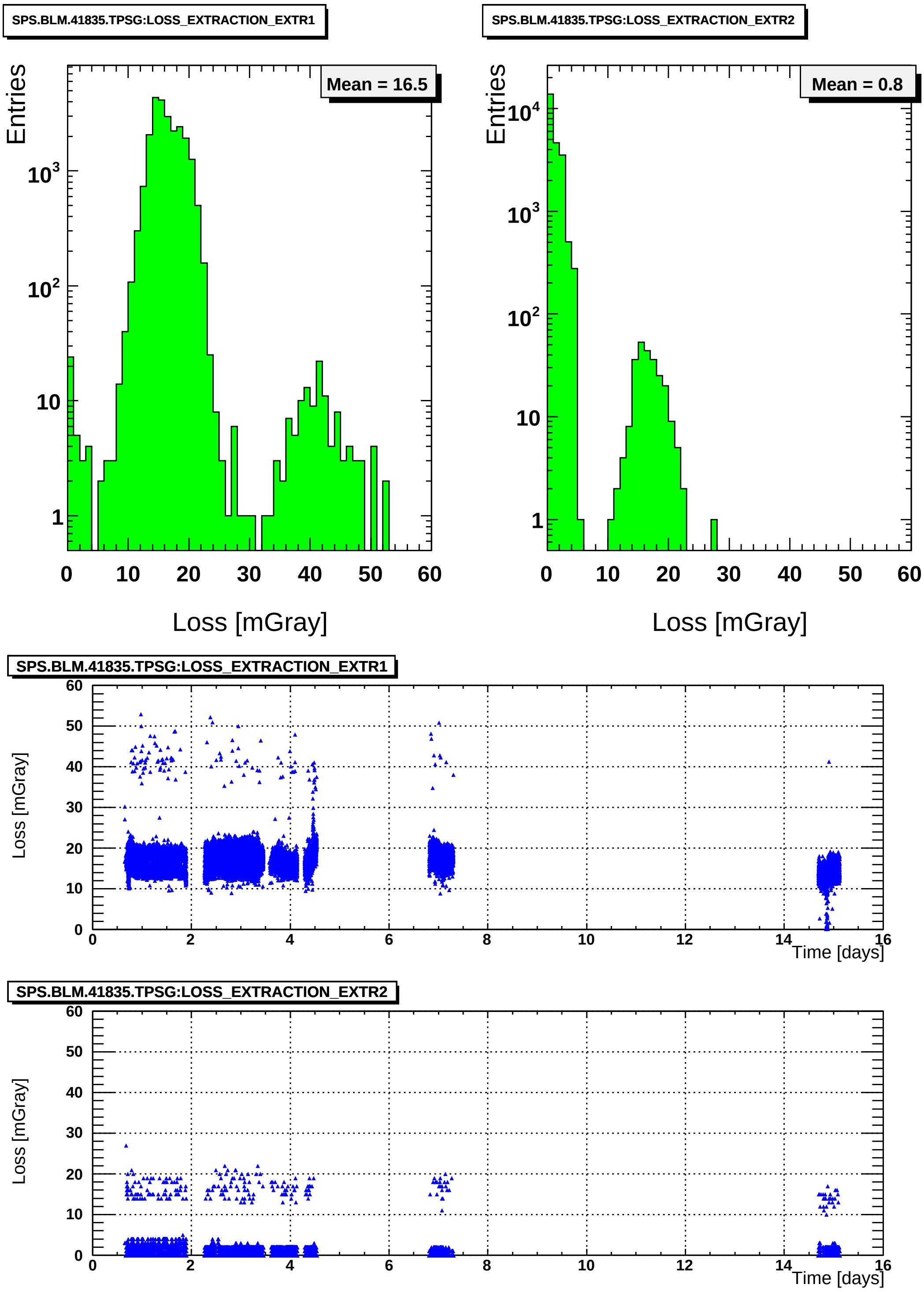


Figure 10: Distribution and time evolution of the measured beam loss on the BLM at the TPSG. A loss of 20 mGray corresponds to 10^{10} protons lost on the TPSG.

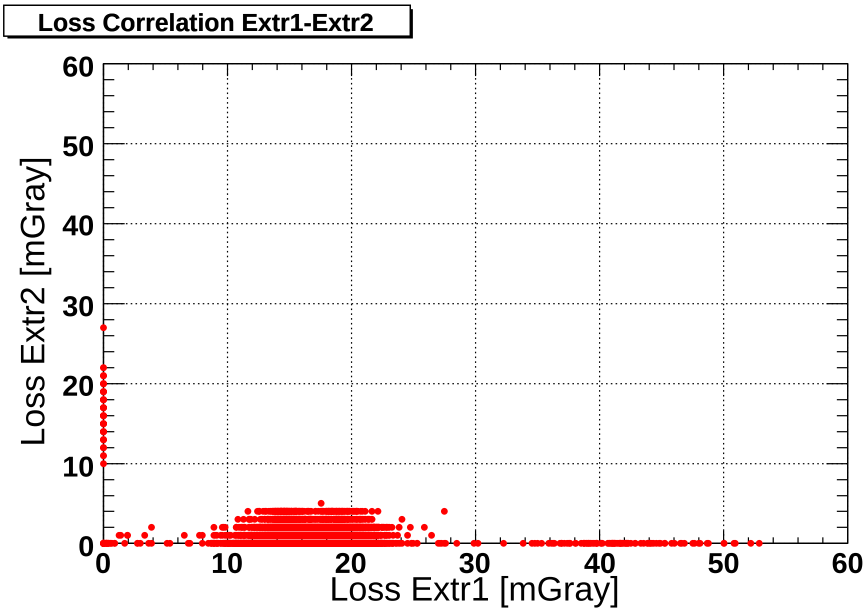


Figure 11: Correlation of the beam loss measured for extraction 1 and extraction 2 by the BLM installed at the TPSG. For large losses on extraction 1, there is no loss for extraction 2 because the beam dump is triggered by the BLM. The large losses on extraction 2 correspond to case where there is no extraction (and therefore no loss) for extraction 1.

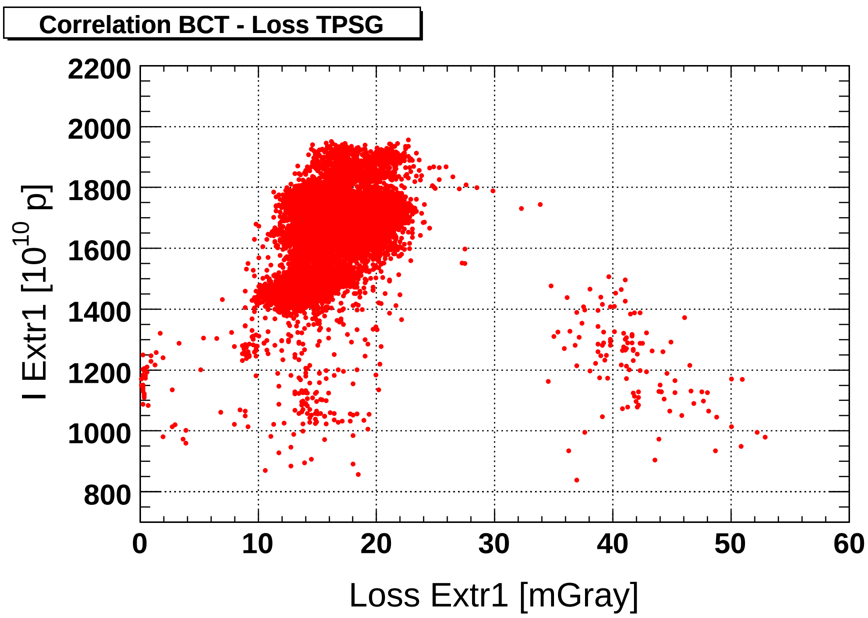


Figure 12: Correlation of the beam loss measured for extraction 1 by the BLM installed at the TPSG with the extracted beam intensity as measured by the BCT in front of T40. There is a clear correlation between large losses and low intensity.

6.2 Transfer line losses

The distribution of the losses on all the monitors from the extraction channel to the T40 target is shown in Figure 13. The thresholds are indicated by the red line. The high threshold near monitors number 14 and 15 correspond to the location(s) just behind the TED dump in TT40 where losses can be very high whenever the beam is extracted to that dump. The threshold of 5 mGray has been chosen to allow operation with high intensity beam in the presence of the 200 μm thick Carbon OTR screens since those screens generate losses of up to 2 mGray.

6.3 Exceptional BLM Triggers

Two special 'events' have been observed with respect to beam loss in the period under study. They are shown in Figure 14.

1. The first event concerns losses in the extraction channel, with one major loss event on the second extraction of the SPS cycle starting 08-10-2007 at 06:27:24 (UTC) with a peak loss on the first BLM of 124 mGray and large losses on all extraction monitors. The first batch was not extracted due an erratic interlock by the SPS beam position surveillance (section 4). The beam position in the transfer line and in the SPS before extraction were normal. In that specific cycle there must have been an unusually large amount of beam in the abort gap.
2. In the TT41 transfer line itself (BLM monitor numbers larger than 15) there is a unique event where monitor TT41.BLM.410307 exceeds the threshold of 5 mGray. This event occurred on the SPS cycle starting at 08-10-2007 at 10:03:00 (UTC) on extraction 1 and lead to a latched BLM interlock that was reset 13 minutes later by the OP crews. The BLM is installed at a vertical aperture limitation in the first TT41 arc cell. The losses on the other BLMs were normal and the beam position in the transfer line and in the SPS before extraction were also normal. The logging of the extraction and the TT40 transfer line power converters does not indicate anything abnormal. Unfortunately the logging of the TT41 power converters did not work during that period.

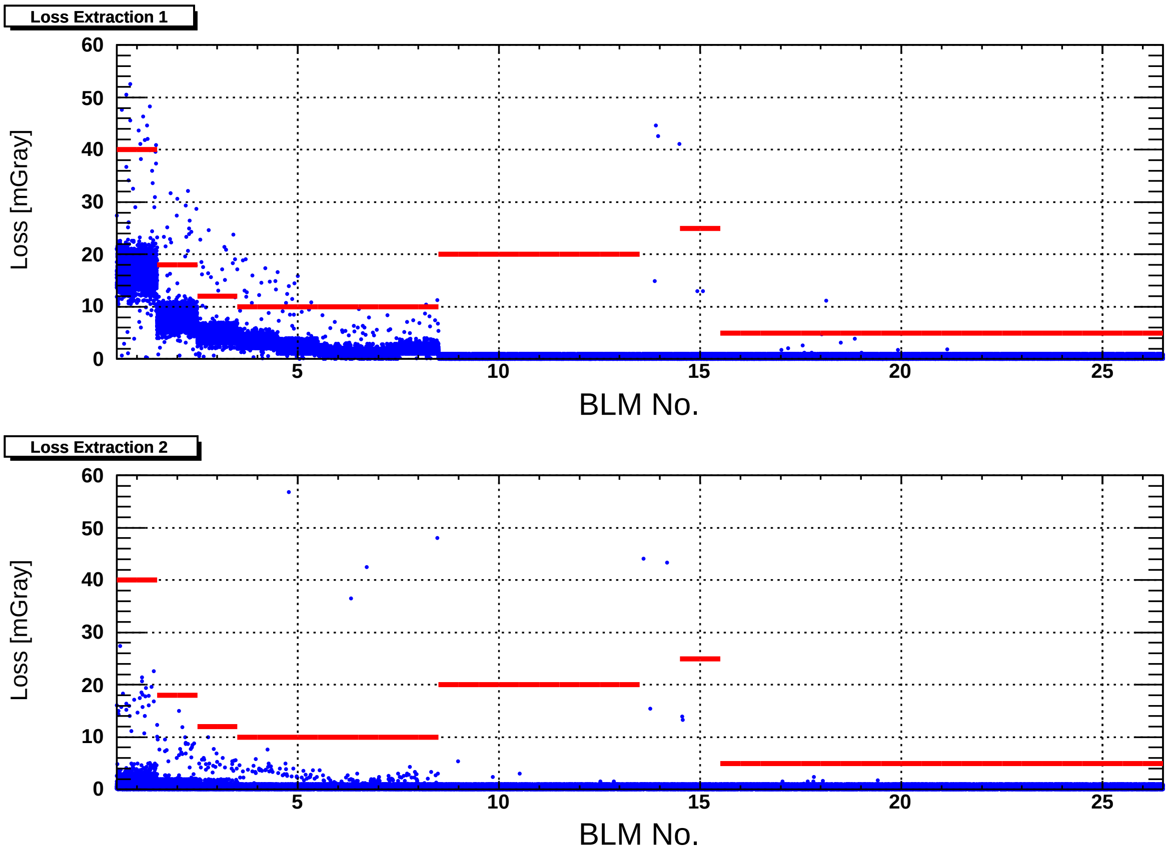


Figure 13: Loss distribution from the extraction to target T40 for the two extractions. Except for some losses when the beam is extracted to the TED, there are no visible losses in the TT41 transfer line. BLM number 14 is located just behind the TED dump and has a threshold of 100 mGray that is outside the scale of the plot.

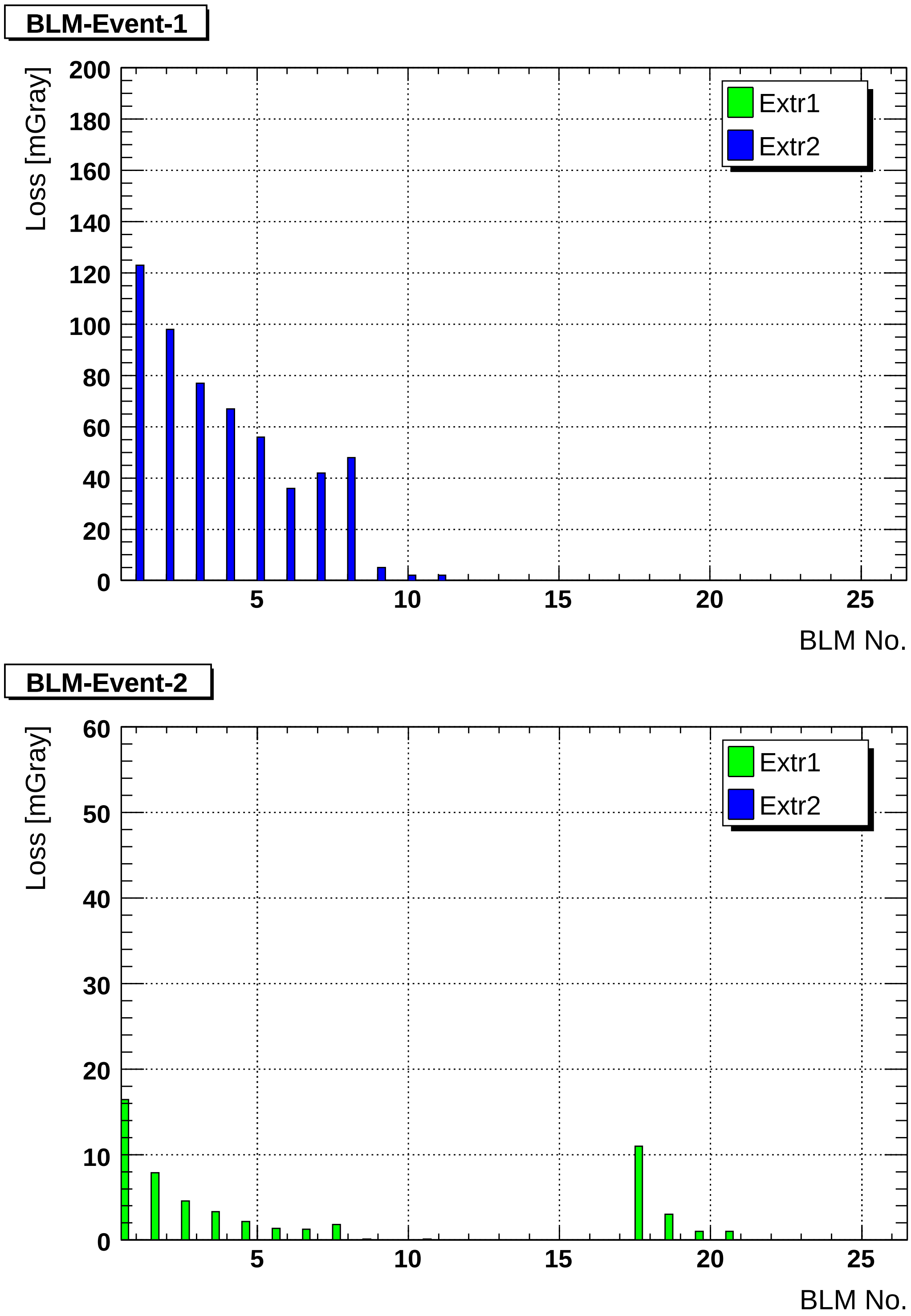


Figure 14: Loss distribution for the two exceptional beam loss events. Top: largest loss observed in the extraction channel (BLM numbers 1 to 8) for extraction 2 on 08-10-2007 at 06:27:24 (UTC). Bottom: the only event with losses above threshold in the TT41 transfer line on 08-10-2007 at 10:03:00 (UTC). The loss is at BLM TT41.BLM.410307 (number 17) which corresponds to a vertical aperture limitation.

7 False Interlocks

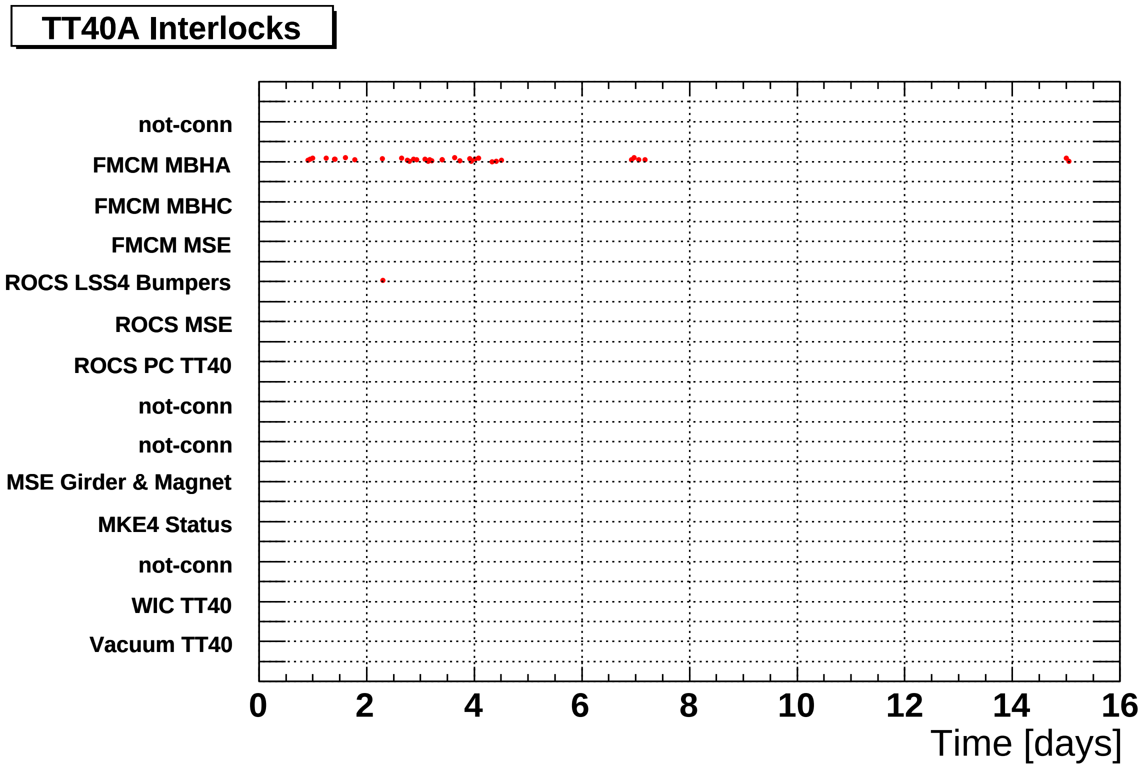
An analysis of the logged beam position and beam loss data is not able to explain the 3% of extractions that were not triggered. The estimated rate of interlocked cycles is less than 1%. To evaluate the rate and source of possible false interlocks due to measurement errors or timing delays in the front-end systems, the logged interlock system data was analyzed and correlated to the logged SPS BCT data.

It is not always straightforward to distinguish real interlocks from false interlocks from the logging data alone. In some cases the interlocks are real because the transfer line is switched off or because tests were performed for a short time. It is therefore necessary to filter out as much as possible real interlocks. In the analysis of the beam interlock data, false interlock candidates are identified as cycles where the interlock data indicates the presence of a SINGLE interlock for a given Beam Interlock Controller (BIC) module. The simultaneous occurrence of two false interlocks within the same module is extremely unlikely. The distribution in time of such false interlock candidates is shown in Figures 15 and 16. The interlock system input names refer to the following keywords:

- **FMCM :** the FMCM (Fast Magnet Current Change Monitor) is a device that detects powering failures from the voltage of a magnet circuit. The FMCM is extremely sensitive (down to relative changes of less than 10^{-4}) and very fast (μsec reaction times). FMCMs are installed for the most critical electrical circuits/magnet strings.
- **ROCS :** refers to the power converter current surveillance performed on groups of converters by the power converter front-end control system (ROCS).
- **WIC :** refers to the normal conducting ('warm') magnet interlock system that protects the magnets against overheating.
- **TBSE :** is a personal protection beam stopper.

The large majority of false interlock candidates are concentrated on very few channels, mostly beam instrumentation interlocks. The dominating source of random interlocks, with 2.3% of the cycles, is the position surveillance of the SPS beam before extraction (see Section 4) that is indicated by **LSS4 BPM** in BIC module TT40B. This is in agreement with online observations made in the control room during the CNGS run. The BLM interlocks of TT40 (BIC module TT40B) and TT41 (BIC module TT41B) and the beam position interlock of TT41 (BIC module TT41B) follow with 0.4% to 0.6%. It must be noted that one of the BLM interlocks and some BPM interlocks were real, see sections 6.3 and 5.1. But a detailled analysis shows that the majority of the interlocks are indeed false interlocks. The most frequent cause of false interlock is a delayed transition of the interlock signal: to maximize the safety of the system, the normal state of the beam instrumentation and powering interlocks corresponds to an interlocked extraction. For the case of beam instrumentation green light for extraction is given a very short time (few milliseconds) before charging of the extraction kicker pulse forming networks. A timing jitter of a few milliseconds is sufficient to provoke a false interlock.

False interlocks related to powering are rare. The FMCM on the MBHA magnet string (BIC module TT40A) is responsible for erratic interlocks on 0.15% of the cycles, because the interlock thresholds was set too tight. The interlocks on the TT41 power converter surveillance (**ROCS TT41** in module TT41A, 0.3% of the cycles) are mostly due to target steering (beam centering in the muon detectors).



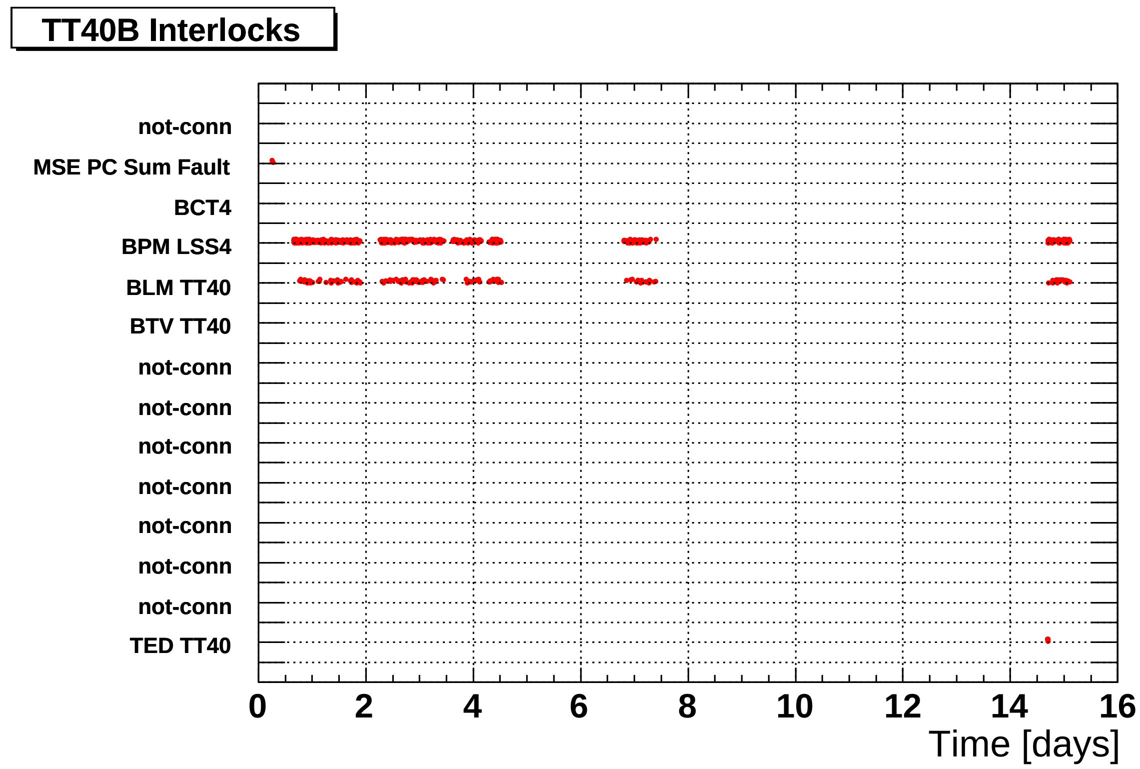


Figure 15: Time distribution of (possible) false interlocks for the two Beam Interlock Controller crates (TT40A and TT40B) that handle interlocks from the LSS4 extraction region and from the TT40 transfer line. The vertical scales corresponds to the different input channels.

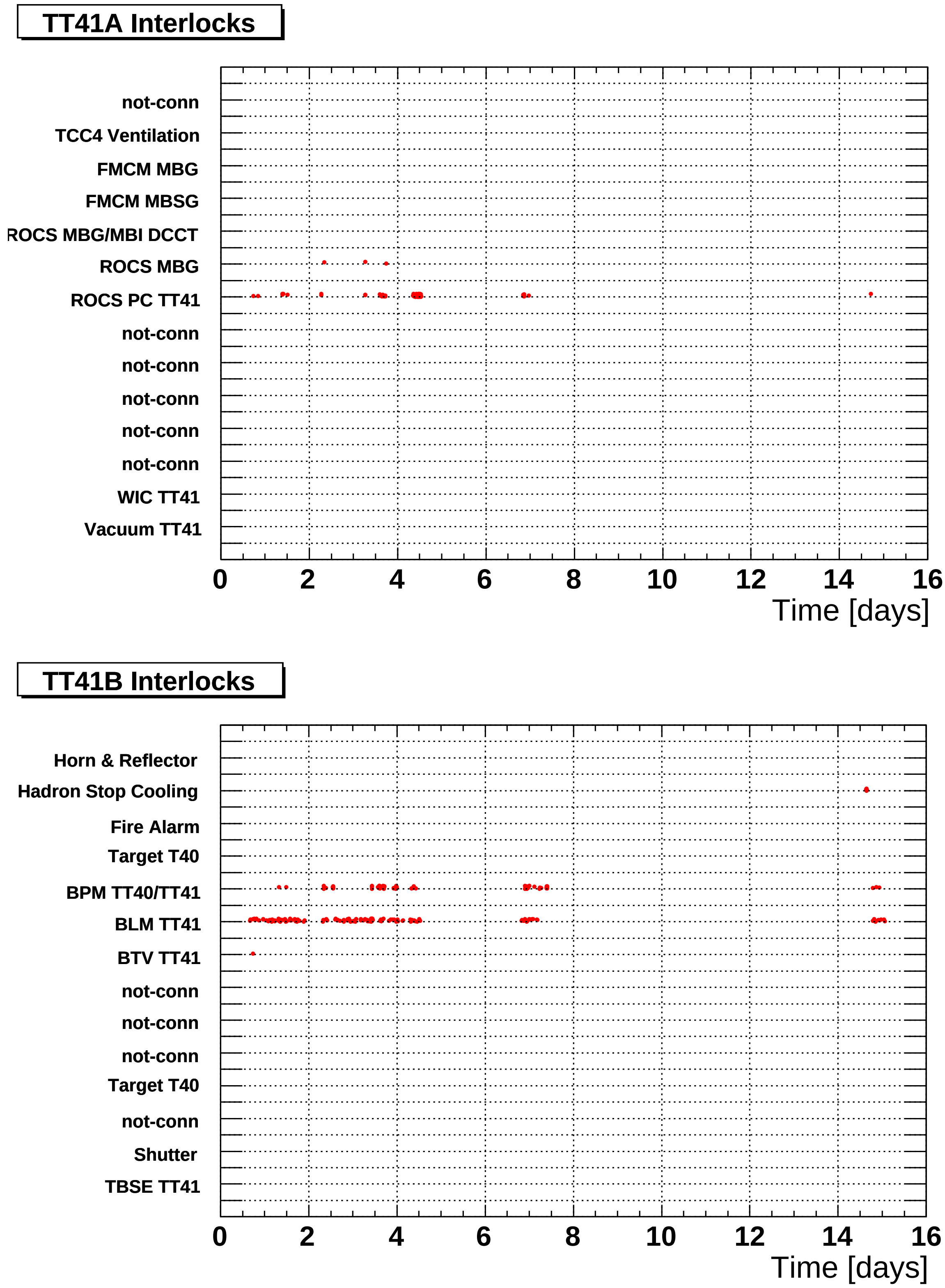


Figure 16: Time distribution of (possible) false interlocks for the two Beam Interlock Controller crates (TT41A and TT41B) that handle interlocks from the TT41 transfer line and the CNGS target and secondary beam area. The vertical scales corresponds to the different input channels.

8 Conclusion

The stability of the CNGS beam at 400 GeV/c in the SPS, in the transfer line and on target T40 in 2007 was excellent. During the high intensity operation period all extractions hit the target well within the tolerances.

Beam losses were usually stable, with larger losses in the extraction channel in 0.3% of the cycles. The losses are due to the presence of $\approx 1\%$ more beam in the beam gap than for normal cycles. Since only the second extraction is dumped, the lost intensity corresponds to only about 0.15% of the total beam intensity accelerated in the SPS ring.

The fraction of extractions lost due to false interlocks is around 3%. The second extraction is lost twice as frequently than the first extraction. The majority of false interlocks are caused by inputs from beam instrumentation. The dominating source of false interlocks is the position interlock on the SPS beam position just before extraction. Since this interlock had to be added into the SPS position monitor front-end control system (MOPOS) that was known to be fragile, this does not come as a complete surprise. It is planned to build a new system for this interlock in the near future.

The 3% loss of integrated intensity due to those erratic interlocks from such a new and complex interlock system is reasonably small compared to the 20% overall downtime of the SPS (includes the SPS injectors). The aim for the 2008 run is to bring the false interlock rate down to 1% or less.

References

[1] K. Cornelis $etal.$, *CERN Neutrinos to Gran Sasso (CNGS) : Results from Commissioning*, CERN-AB-2007-039.

[2] E. Carlier $etal.$, *High Intensity Commissioning of the SPS LSS4 extraction for CNGS*, CERN-AB-2007-048.

[3] J. Wenninger, *Procedures for the Commissioning of the Beam Interlock System for the CNGS and SPS-LHC Transfer Lines*, LHC-CIB-TP-0001.

[4] J. Wenninger, *Interlocked Equipment ot the CNGS and LHC Transfer Lines*, LHC-CIB-ES-0003.

[5] J. Wozniak, V. Baggiolini, D. Garcia Quintas, J. Wenninger, *Software Interlock System*, Proceedings of ICALEPCS07, Knoxville, Tennessee, USA

[6] The documentation and description of the interlock tests can be found at https://sps-mp-operation.web.cern.ch/sps-mp-operation/.

[7] J. Wenninger, R, Giachino, V.Kain, *Commissioning of the Beam Interlock System for the TT40 and TT41 Transfer Lines of the SPS*, CERN-AB-Note-2007-002.

[8] J. Wenninger, V. Kain, M. Meddahi, *Beam Stability and Optics Studies of the CNGS Transfer Line*, CERN-AB-Note-2007-008.